

Crossing Boundaries: Managing Invasive Species and Water Quality Risks for Coastal Boat Hulls in California and Baja California

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How can this report help California's coastal boaters?

fouling organisms that accumulate on boat hulls reduce vessel speeds and increase fuel consumption.¹ Copper antifouling paints are widely used to slow the growth of hull-fouling species. Unfortunately, scientists^{2,3} and regulatory agencies^{4,5} have determined that copper leached from antifouling paints can accumulate in boat basins to levels that harm marine life.

To address copper pollution from antifouling paints, regulatory agencies are monitoring boat basins. Some regulatory programs have been created or proposed. For example, copper emissions from antifouling paints in Shelter Island Yacht Basin of northern San Diego Bay must be reduced by 76% during 2007-2022 under a Total Maximum Daily Load (TMDL) regulatory program.⁶ TMDL programs have been recommended to reduce levels of copper and zinc in the major Southern California recreational boating harbors of Marina Del Rey⁷ and Newport Bay.⁸ In 2011 the Washington State Legislature passed a law that by 2020 would restrict copper content to 0.5% in antifouling paints that are applied to recreational boats up to 65 feet long.⁹ If restrictions on copper antifouling paints spread beyond northern San Diego Bay, more California boat owners will need the boating industry's assistance in applying, maintaining and controlling fouling on alternative hull coatings.

These issues are complicated by the fact that some hull fouling species are "invasive." In other words, they can grow aggressively and outcompete native species for space and food, disrupting local ecosystems and affecting harbor structures. Scientists are finding that some invasive hull fouling species can tolerate copper antifouling paints,^{10,11} making them more difficult to control. By growing over the antifouling paint and thus creating a nontoxic surface, some copper tolerant species also facilitate fouling by nontolerant species.¹²

Regulatory agencies are concerned about transport of invasive species on hulls of boats, including recreational boats. The California Aquatic Invasive Species (AIS) Management Plan, Strategy 2c: Recreation calls for limiting new AIS introductions through recreational boating, fishing, diving and other water-based activities.¹³ Thus, boat owners will also need the industry's assistance in controlling invasive species among hull fouling.

Boat owners, boating businesses, agency staff and policy makers need reliable information to make

decisions on balancing invasive species, water quality and cost considerations in managing hull fouling. The boating industry provides options to assist boat owners in managing risks to water quality that are posed by toxic antifouling paints and risks to coastal ecosystems and structures that are posed by invasive, hull fouling species. Cost effective solutions are important to California boaters, who generally earn a moderate income.¹⁴

We conducted the research on which this report is based in order to determine costs and "capacity" of the boating industry ("supply side") to provide California's coastal boat owners with supplies and services for controlling fouling on four broad categories of hull coatings: 1) copper antifouling paint (hereafter "copper paint") and three alternatives, namely 2) zinc paint, 3) nontoxic epoxy hull coatings and 4) nontoxic slick hull coatings. Slick coatings include silicone and the more durable siliconized epoxy. For examples and more information on nontoxic epoxy and slick coatings, see our *Alternative Antifouling Strategies Sampler*.¹⁵

Capacity includes supplies, equipment and knowledge needed to handle boats, prepare hulls, apply coatings, and periodically clean them to remove fouling growth. Capital investments and staff training may be required to acquire capacity that is specific to the characteristics of alternative hull coatings. For example, currently, old copper paint must be stripped from the hull before a nontoxic hull coating is applied. An alternative may need to be heated and rolled onto the hull. Slick hull coatings require a special primer to enable them to adhere to the hull. Precautions must be taken to prevent a boat with a slick coating from slipping when being hauled from the water or when standing on blocks in the boatyard or on a boat lift. Hull cleaners in San Diego and Santa Barbara have advised us that powered brushes and more frequent cleaning are necessary to keep up with the rapid accumulation of fouling on nontoxic hull coatings. Our field research found that nontoxic coatings fouled more quickly than copper hull coatings.¹⁶

Because California's coastal boaters travel to and from the Sacramento-San Joaquin Delta and the Baja California peninsula, we surveyed boating industries in these areas, as well as on California's coast. Recreational boats moving among inland waterways, commercial boats and ships are beyond the scope of this report.

The "supply side" research presented in this report answers four questions that are critical to the water quality and invasive species risk management decisions noted above.

1. What strategies are available from the boating industry to manage risks created by copper polluted water and invasive species?
2. What is the industry capacity to provide these risk management strategies?
3. What is the cost of using each risk management strategy?
4. What is the role of education in risk management?

We also asked boating industry members about boater travel patterns and awareness of alternatives that may

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Hull cleaner's boat with powered brushes and other equipment

influence risks and opportunities to manage risks.

Most of the material presented in this report is based on a peer-reviewed, journal article:

Johnson LT and Fernandez LM. 2011. A binational, supply-side evaluation for managing water quality and invasive fouling species on California's recreational boats. *Journal of Environmental Management*: 3071-3081.

We recommend reviewing that article for in-depth statistics and analyses.

Background: What are the risks?

Impaired water quality

Although the coatings and hull maintenance industries have provided nontoxic and other hull coating alternatives, as well as companion fouling control strategies, the market is dominated by copper antifouling paints.¹⁷ Research has indicated that passive leaching of copper from antifouling paints contributes to elevated copper levels found in some California coastal boat basins.^{18,19}

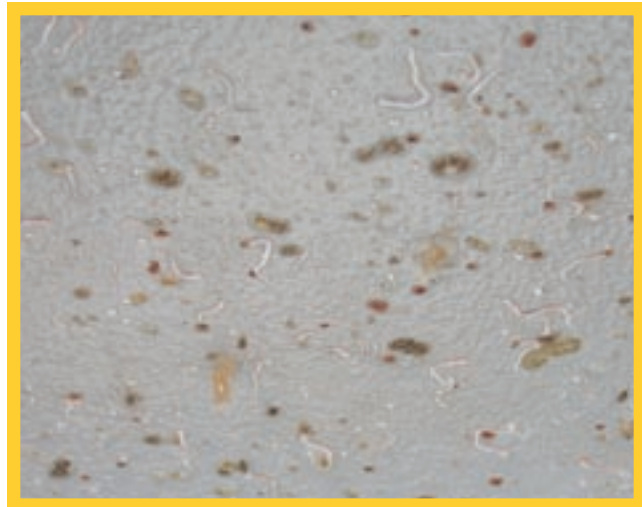
The standard of 3.1 micrograms per liter ($\mu\text{g/l}$) for chronic levels of dissolved copper²⁰ is based on laboratory studies that investigated its toxicity to mussels, oysters, scallops, crabs and sea urchins, which are typical species found in coastal harbors. When exposed to dissolved copper at concentrations from 3.0 to 10.0 $\mu\text{g/l}$, these species showed various effects, including reduced or abnormal: embryo growth, development, swimming and survival; larval growth and survival; adult growth, spawning and survival; and adult digestive, reproductive and muscle tissues.^{21,22,23,24,25,26,27,28,29,30,31} Some of these studies and others^{32,33} found that many of the above effects became more severe and that feeding, respiration, and waste elimination of adult mussels were also affected at dissolved copper levels from 10.0 to 29.0 $\mu\text{g/l}$.

Copper has been shown to have adverse effects on salmon sensory processes.³⁴ It also causes problems in the gills, kidneys, tissues and sensory receptors of fish in general.³⁵

Thus, exposure to levels of dissolved copper, which are addressed by TMDL programs for some of California's coastal boat basins, may impair and sometimes kill species that occur in marina water. We refer to metal-based antifouling paints (copper and zinc) as toxic and we refer to epoxy and slick (siliconized) hull coatings that lack such toxins as nontoxic. Antifoulants based on toxic organic chemicals and the potential for biotic ligands in marina water to mediate environmental effects of heavy metals are beyond the scope of this report.

Invasive species

By travelling on boat hulls, fouling species may be carried beyond their natural range.^{36,37,38} They may establish in new environments and become invasive. About 34% of all California recreational boaters take 1-5 trips per year and 16% take from 6 to over 20 trips per year that are over 100 miles from home.³⁹ Our goal is to



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Fouling on boat hull with nontoxic coating. Note the long, slender, white Hydroides tubeworms that are often difficult to remove.

assist the boating community in responding to regulatory concerns about transport of invasive species carried on hulls of coastal recreational boats.

Invasive species create ecological and economic risks. They may outcompete native species for resources, such as food and living space, and reduce overall biodiversity.⁴⁰ They may cause structural damage, for example, the Teredo shipworm is estimated to cost the United States \$205 million annually in control costs, losses and damages.⁴¹ The burrowing Australasian isopod *Sphaeroma quoyanum* has invaded San Francisco Bay,⁴² riddling soft shores with quarter-inch wide holes, and causing shorelines in some regions to erode and retreat by several yards.⁴³

Further, recent studies have shown that an invasive species' ability to dominate native species can be enhanced in copper polluted environments.⁴⁴ This advantage may be the result of copper tolerance among some fouling species. We will explore the science behind copper tolerance in a later section.

Question 1. What risk management strategies are available?

This report aims to answer risk management questions with respect to several strategies. The first risk management strategy is using a coating on the hull of a boat. We considered four broad categories of hull coatings: 1) copper paint (many copper-based antifouling paints), 2) zinc paint (many zinc-based antifouling paints), 3) nontoxic epoxy coating (various durable/hard nontoxic coatings), and 4) nontoxic slick coating (various silicone or siliconized-epoxy coatings).

In this report, "alternative coatings" refer to all three categories of non-copper products, and "nontoxic coatings" refer only to the epoxy and slick categories.^A This is because zinc, like copper, is a toxic, heavy metal. Slick coatings are also called "foul release" because fouling organisms adhere poorly and can be removed by light

A Examples of nontoxic hull coatings may be found in our "Alternative Antifouling Strategies Sampler" at http://ucanr.org/sites/coast/Nontoxic_Antifouling_Strategies/. The industry continues to develop alternative hull coatings.



In-water hull cleaner scrubs boat hull with handheld pad

brushing or water spray.⁴⁵ Field tests showed that fouling began to be released from boat-mounted test panels with a silicone hull coating at 4 knots and that some fouling still remained at 12 knots.⁴⁶ This suggests that nontoxic slick coatings need to be cleaned, unless a boat regularly achieves speeds well above 12 knots.

Other risk management strategies included in our study are considered “companion strategies” because they are typically used to supplement the effectiveness of a hull coating. These include in-water hull cleaning, boat lifts and slip liners. Hull cleaning is typically performed by a diver who wipes away fouling growth that has accumulated on the hull. Boat owners should consult the marina/harbor authority regarding hull cleaning policies before selecting this option.

Boat lifts and slip liners prevent hull fouling by isolating the hull from environmental conditions that would allow organisms to grow on it. A boat lift elevates a boat above the water. Note that boats with slick hull coatings may require additional care in lifting and extra fastenings to prevent them from slipping off a boat lift. A slip liner is placed in the slip, the boat is driven into it, and the liner is closed, creating a closed pool of water. Enough freshwater may be added to this pool so that marine fouling organisms cannot survive. Alternatively, a liquid chlorine product that is permitted by state regulations for this purpose may be added according to the product’s label; the chlorine level must fall below a specified concentration before the slip liner may be reopened.^{B, 47} Before deciding to use a slip liner, boat owners should determine state and local regulations on using freshwater or liquid chlorine with them. Boat owners should also consult the marina or harbor authority on policies regarding boat lifts and slip liners before choosing to use them. Boat owners should consult

B The April 2007 County of San Diego Department of Agriculture, Weights and Measures, “Official Notice to Dock Masters and Marine Suppliers,” discusses proper use of liquid chlorine products in slip liners. It is excerpted for educational purposes in “Alternative Antifouling Strategies Sampler” at http://ucanr.org/sites/coast/Nontoxic_Antifouling_Strategies/.

boat lift and slip liner vendors for instructions on cleaning fouling growth that may accumulate on them.

Methods: What did we do?

To answer the four research questions posed above, we surveyed marina operators, hull cleaning companies, and boat repair yards along California’s coast, in parts of the Delta of California’s Sacramento and San Joaquin Rivers (Delta), and in three major boating areas of the Baja California peninsula’s coast during 2008. Throughout this report, ‘marinas’ refers to marinas, harbors and yacht clubs. The sample included 92 California and 8 Mexico marina managers; 28 California and 5 Mexico boat repair yard operators; and 23 California and 4 Mexico in-water hull cleaners. However, not every participant answered each question in the survey, so keep in mind that the resulting statistics may be based on a varying number of responses.

We also included slip liner and boat lift company representatives in the survey. Because they were fewer in number, our sample included 3 slip liner companies from California, Oregon and Washington, and 17 boat lift companies from across the United States. No slip liner or boat lift companies could be found on the Baja California peninsula. Respondents answered questions relating to risks, risk management capacity and costs. In addition, some questions shed light on the role of education in balancing water quality and invasive species management in California and across the international border.

The target sample was 30% of each industry group, which is appropriate for populations under 1,000.⁴⁸ We identified a total of 575 boating businesses of which we sampled slightly over 30% of marinas, boat yards and slip liner companies and slightly under 30% of hull cleaner and boat lift companies. Itinerant service providers were not included, as they could not be identified via means that were available to us (industry lists, Internet sites and referrals).

California survey regions are depicted in Figure 1. Baja California peninsula survey regions are depicted



Two boats in slip liners in Southern California marina

in Figure 2. Note that Northern California includes the North Coast and San Francisco Bay Area (Bay Area) Regions; also, Southern California includes the South Coast and San Diego regions. For this report, Mexico and Baja California refer to three boating areas in the states of Baja California and Baja California Sur. Data were analyzed using statistical software STATA™ and SPSS™ and by qualitative methods. Results are discussed below.

Question 2. What is the industry capacity for risk management?

Marinas

We surveyed marinas to determine their capacity for boat storage, costs for using this capacity, their perceptions of boating traffic (sources of overnight visitors) and other customer behaviors that affect these risks.

Average marina capacity was 384 slips in California and 206 slips in Mexico. Tenants of California marinas stayed from two months to 48 years with an average stay of 9.4 years; no Mexico marinas reported boat tenure.

Marinas reported on average that 48% of boats rarely leave the marina. Such boats may have a greater effect on local water quality than active boats, by continuously leaching toxins from antifouling paints. California marina operators believed on average that 64% of their tenants had copper paint, 12% had zinc paint, and 10% had nontoxic hull coatings on their boats.

Marinas were also asked about their policies on companion strategies. Nearly all California and all Mexico marinas had boat repair facilities nearby; they were onsite at 20% of California and 25% of Mexico marinas. In-water hull cleaning was permitted at 87% of California marinas and 88% of Mexico marinas. Slip liners were allowed at 47% of California marinas and 88% of Mexico marinas. Boat lifts were permitted at 45% and 38% of California and Mexico marinas, respectively. Thus, boat owners should check with marina management before selecting a companion strategy.

Hull Cleaners

We surveyed hull cleaners in California and Baja California to determine the capacity for managing risks with this companion strategy. Hull cleaning businesses were concentrated in Southern California and the Bay Area. Hull cleaners also responded, although to a lesser extent, from the Central Coast and Baja California. The median^c number of boats serviced per company each year was 260 in California and 100 in Mexico. (The average number of boats cleaned was distorted by some reports of individual cleanings per year.)

Copper paint represented 82% of hull cleaners' business in California. Mexican hull cleaners reported that copper paint represented 100% of their business. (Despite that, one Mexican hull cleaner reported cleaning frequencies for all 4 types of coatings noted below.) This suggests that there is little capacity in terms of knowledge, materials and equipment that are needed to clean alternative coatings.

^c The median is the middle of a range; it more accurately expresses the central point when a few high or low responses distort the mean (the average).



Figure 1. Study regions and counties in California



Figure 2. Study regions and states in Mexico

Hull cleaning times varied, but in general power boats took longer to clean than sail boats. It is important to keep in mind that each coating type and boat length category had a different number of responses, thereby giving different weights to each average. In California 18-22 hull cleaners provided cleaning times (and costs, see below) for copper, whereas there were 5-8 responses for zinc, 6-9 for epoxy and 4-6 for slick. In Mexico 3 hull cleaners responded for copper, only. Hull cleaning in California required an average of 1 person and 56 minutes and in Mexico required 1.5 persons and 105 minutes, depending on the type and length of the boat (Figure 3a-b). The differences likely reflect lower labor costs in Mexico and possibly a greater use of power equipment in California.

The survey also investigated hull cleaning frequencies, which are needed to calculate total cleaning costs for using different coatings. The numbers of hull cleaners who responded to this question varied among seasons: in

California 20-21 respondents had serviced copper paints, 1-2 had serviced zinc paints, 5-6 had serviced nontoxic epoxy coatings and 3 had serviced nontoxic slick coatings; in Mexico 3 respondents had serviced copper but only 1 had serviced zinc, epoxy and slick coatings.

Cleaning non-copper hull coatings may require different cleaning frequencies and equipment than are used for copper hull coatings. The fact that few hull cleaners reported cleaning alternative hull coatings suggests a low overall industry capacity to clean them.

Regional and seasonal differences in hull cleaning frequencies for copper paints are shown in Table 1 and Figure 4. They do not include data from hull cleaners who did not report for all four seasons.

The most common cleaning frequencies (boldface font in Table 1) were once per 3-month season in the Bay Area and Central Coast, three times per season in Southern California and four times per season in Mexico. Statistical analyses suggest that geographic region has a moderate, significant influence on hull cleaning frequencies for copper paints, as represented in Table 1. These data suggest that more frequent cleanings are needed farther south where the water is warmer. Although there is a moderate correlation between the season and the number of cleanings, these were not statistically significant. (Alternative coatings received too few responses for such analyses.)

Figure 4 shows the mean (average) number of cleanings per three-month season for copper paint in California (20 responses) and Mexico (3 responses). They were cleaned most often in the summer.

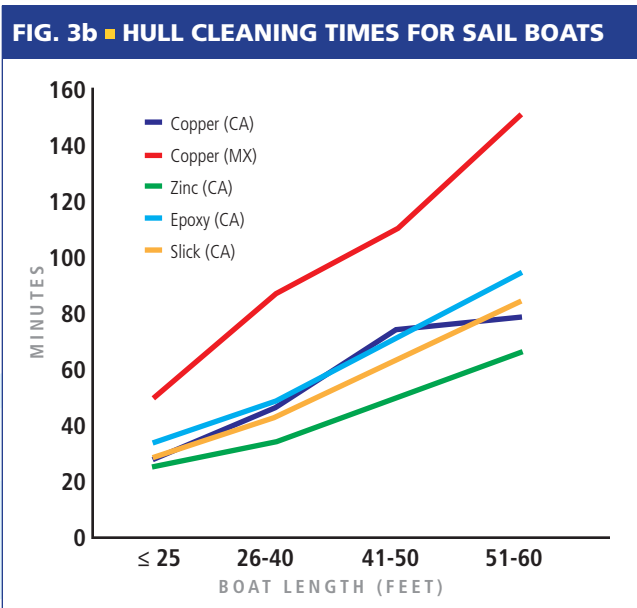
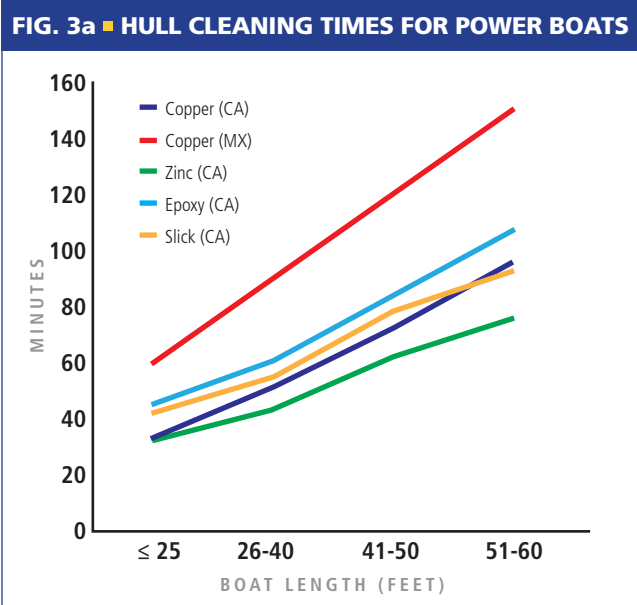
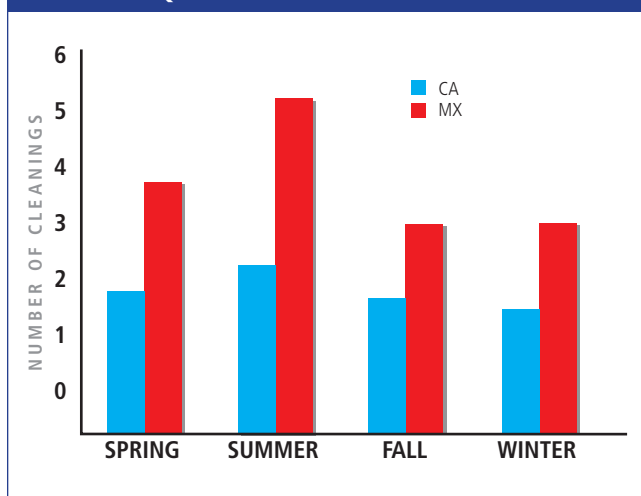


	TABLE 1		
	Seasonal hull cleaning frequencies for copper antifouling paint in three major regions. Whole numbers are number of hull cleanings per 3-month season. Percentages are the percent of total responses for each cleaning frequency. Most common hull cleaning frequency for each season in each region is shown in boldface.		
	Bay Area + Central Coast	South Coast + San Diego	Mexico
Spring	1 (78%) 2 (11%) 3 (11%)	1 (9%) 2 (9%) 3 (73%) 6 (9%)	4 (100%)
Summer	1 (78%) 2 (11%) 3 (11%)	2 (8%) 3 (64%) 6 (27%)	4 (67%) 8 (33%)
Fall	1 (89%) 3 (11%)	1 (18%) 3 (73%) 6 (9%)	2 (33%) 4 (67%)
Winter	1 (89%) 3 (11%)	1 (20%) 3 (80%)	2 (33%) 4 (67%)

FIG. 4 ■ AVERAGE SEASONAL CLEANING FREQUENCY FOR COPPER



Cleaning frequencies of alternative hull coatings varied among California regions and were based on fewer responses than for copper paint. California hull cleaners serviced zinc once every season in the Bay area. In San Diego, zinc was cleaned four times in summer, and three in winter (no data were provided for spring and fall). Bay Area hull cleaners serviced epoxy and slick coatings 1-3 times every season. Southern California (South Coast and San Diego) hull cleaners serviced epoxy and slick 6-12 times per entire season in spring, summer and fall, and only 6 times in winter. The one hull cleaner who reported servicing zinc, epoxy and slick coatings in Mexico cleaned all of them 4 times per season year-round.

Results indicate that hull cleaning services are readily available for boaters in the Bay Area, Southern California and Mexico. Because so few hull cleaners reported experience with zinc and nontoxic coatings, the industry would need to increase capacity to control fouling on them if restrictions on using copper paints spread beyond northern San Diego Bay.

Boat Repair Yards

Much like the data from marinas and hull cleaners, copper paints dominated boat yards' business. The average number of boats to which each boat yard applied copper paint was 511 per year in California and 78 per year in Mexico. The average percent of business represented by copper paint applications was 78% in California and 75% in Mexico. California boat yards reported on average they applied zinc coatings to 14 boats per year, nontoxic epoxy coatings to 23 boats per year and nontoxic slick coatings to 1 boat per year. A total of 27 California boat yards responded to these questions; 4 Mexico boat yards reported applying copper paints; 1 Mexico boat yard reported applying zinc paints to 10 boats per year; no Mexican yards reported applying nontoxic coatings.

Although approximately half of boat yards in both California and Mexico would recommend alternatives to copper paints, 85% of boat yards in California reported 0% of business from nontoxic coatings (no boatyards in

Mexico provided data). For the few boat yards that did report applying nontoxic coatings, copper represented a much lower percentage of business overall (70%) than it did for the yards that did not apply any alternatives (95%). Yards that applied nontoxic coatings were also much larger, servicing significantly more boats per year than the yards that only applied copper paints, and were all located in California. This suggests generally very little experience applying nontoxic hull coatings, especially at the smaller boat yards.

In order to switch to a nontoxic coating, currently the old, copper paint must be stripped.^D The median number of boats each yard stripped of old paint was 17.5 per year for both California and Mexico. The average number of boats stripped per year was 34 in California and 22 in Mexico; averages are higher than medians due to a few high-capacity boat yards.

California boat yards reported the mean service life was 2.5 years for copper, 1.8 years for zinc, 3.0 years for epoxy and 5.0 years for slick. Mexico boat yards reported a mean service life of 3.5 years for copper and did not report on the other coatings. The results on replacement frequency of alternatives to copper paint are based on very few responses, as few boat yards had experience with them.

Overall, results point to a low, boat yard capacity for applying alternatives to copper paints. Some alternatives require processes and/or equipment that differ from those used for copper paints. Should local, regional or state restrictions be instituted for copper paints, more boatyards would need to acquire the capacity (materials, equipment and specialized knowledge) for working with alternative paints and coatings in order to meet demand. Some boatyards in the San Diego region have developed this capacity. Such "early adopters" may serve as models and peer educators should demand increase for alternatives to copper paints.

When boat yards clean and dispose of biofouling, it is important to properly contain and dispose of organisms so that they are not released into the marine environment. If

^D We have heard reports of investigations into technologies that would avoid the need to strip old copper paint before applying alternative hull coatings.



Hydro washing boat hull before applying new paint in Southern California boat yard

CREDIT: LEIGH JOHNSON



Boat lift in Southern California marina

not properly contained, they present a risk for the release of invasive species.⁴⁹ The majority (85%) of boat yards surveyed collected and disposed of the removed fouling on land, of which 21% disposed of it as hazardous waste.

Slip Liners and Boat Lifts

Although slip liners and boat lifts are less prevalent companion strategies than in-water hull cleaning, we investigated the capacity and costs.

Slip liner companies had more capacity to assist boat owners in managing risks posed by hull fouling, because they could accommodate a larger range of boat lengths. The lengths of slip liners ranged from 13 feet to 100 feet among the three companies surveyed. In contrast, available boat lifts ranged from 4 feet to 40 feet in length among the 17 companies.

One of the three slip liner companies surveyed and no boat lift companies reported having experience with nontoxic hull coatings. Experience with nontoxic slick coatings may be especially pertinent for boat lift companies. This is because boat repair yard managers report that a boat with a slick coating requires extra measures to secure it as it is removed from the water and when it is on a supporting structure.

Overall, a larger percentage of slip liner companies' customers were in Southern California and a larger percentage of boat lift companies' customers were in Northern California and the Delta. More marinas allow slip liners than boat lifts (see section on Marinas, above). Overall, slip liners and boat lifts are not as widely permitted in marinas as in-water hull cleaning (see **Question 2 Marinas**).

These results suggest that there is some capacity to use slip liners and boat lifts to manage water quality and invasive species risks inside marinas, but it is less than that for hull coatings and in-water hull cleaning.

Overall Industry Capacity: How much business does each of the coating types represent?

The marinas, hull cleaners and boatyards reported the percent of their business represented by boats with copper, zinc and nontoxic coatings (Figure 5). The proportion of

business represented by each coating type provides an idea of available capacity to manage water quality and invasive species risks for each hull coating category in terms of experience, materials and equipment that are needed by boat repair yards and hull cleaning companies. The lack of capacity by local boat yards and hull cleaners would affect options that are available for marina managers who may be required or wish to manage these risks in their facilities.

Copper paints dominated each of the service industries' business. (The number of responses to each question varied, so the three categories do not sum to 100% of business.) If a shift away from copper were to occur, the industries would need to increase their capacity to work with alternative hull coatings.

Question 3. What do (boating) industries charge for risk management?

Marinas

Minimum monthly slip rates averaged \$10.14 per foot of boat length in California, and \$12.85 in Mexico. Maximum rates averaged \$18.64 per foot in California and \$21.84 in Mexico. Although not directly related to risk management, these responses were used below to calculate comprehensive costs to use each coating type.

Hull Cleaners

Hull cleaning charges per foot were provided for boat length categories. Results for boats that ranged from "up to 25 feet" to 60 feet are presented in Figure 6a-b. Few responses were provided for larger boats. In general, sail boats cost less to clean than power boats, and cleaning copper hulls in Mexico cost the least overall. The number of responses is the same as for **Question 2 Hull Cleaners** above and most were for costs to clean copper paints in California, suggesting that there is very little capacity for alternative coatings. If cleaning time exceeded the average

FIG. 5 ■ PERCENT BUSINESS FOR COATING TYPE BY INDUSTRY

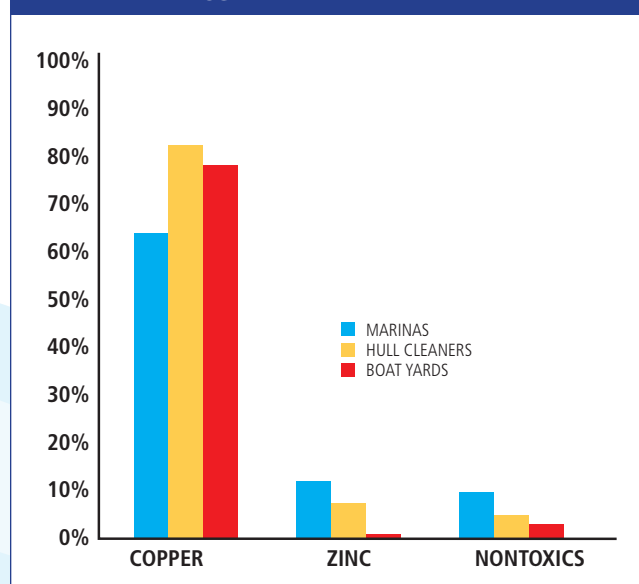
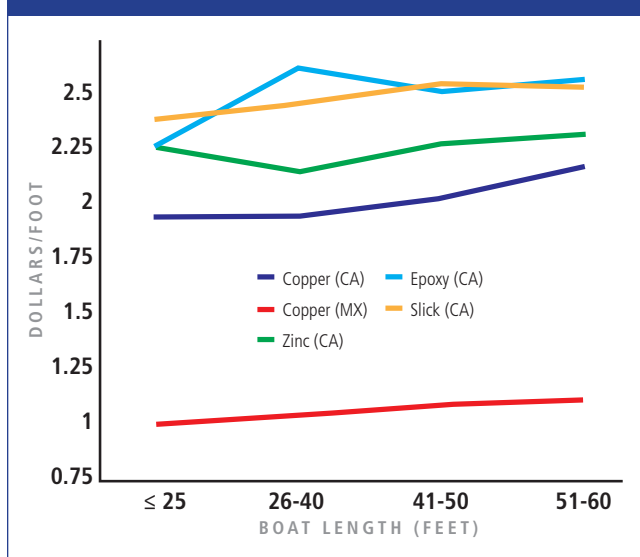


FIG. 6a ■ HULL CLEANING COSTS FOR POWER BOATS



by 25 minutes, additional charges ranged from \$2.68 per foot for copper, to \$4.74 per foot at the most for epoxy, and 80% of hull cleaners surveyed would recommend replacing the hull coating.

Boat Yards

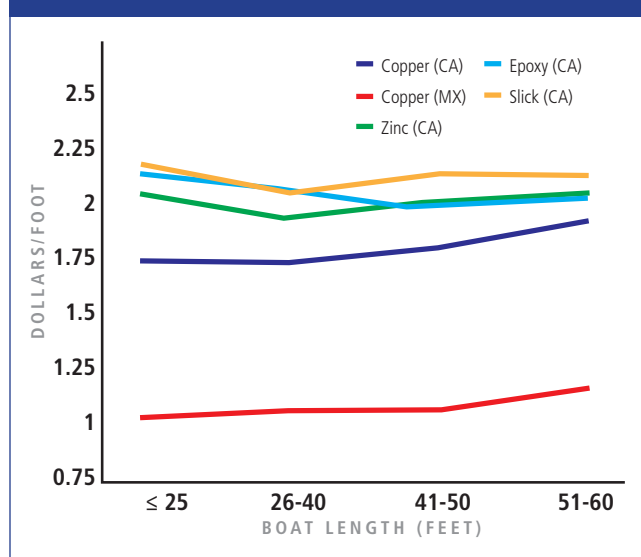
Figure 7 shows costs for boat yards to manage risks by means of hull coating applications. It illustrates the costs per foot that boat yards in California (17-24 responses) and Mexico (2-3 responses) charged to apply copper paint on several length categories. Figure 7 also illustrates application costs for alternative coatings in California only (6-7 zinc, 4 epoxy and 2 slick responses). Mexico boatyards provided no data for applying alternatives. Some respondents did not provide data for all boat lengths. The mean total cost to apply copper paints (including hull preparation but not stripping) to boats increased with boat length. Price per foot typically increases with boat length because the boat's width increases with its length. Applying copper paints in Mexico was the least expensive option.

Currently, when a nontoxic coating is applied for the first time (with the exception of a new boat) the old copper paint must be stripped.^d The median cost to strip a boat hull was \$85 per foot in California and \$12.50 per foot in Mexico. Average stripping costs were distorted and so are not presented because some respondents reported cost per boat, rather than per foot.

In order to offer cost savings to the customer, 63% of boatyards offered hauling out and hull cleaning packages in both California and Mexico. These packages cost an average of about \$11 per foot for the shortest boat to about \$13 per foot for the longest boat.

According to hull cleaners' cost data presented above, the average cost to clean boats ranged from \$1.03 per foot for the shortest sailboats to \$2.59 per foot for the longest powerboats. These results illustrate that even with the hauling out packages, in-water hull cleaning is

FIG. 6b ■ HULL CLEANING COSTS FOR SAIL BOATS



substantially less costly for ongoing fouling control.

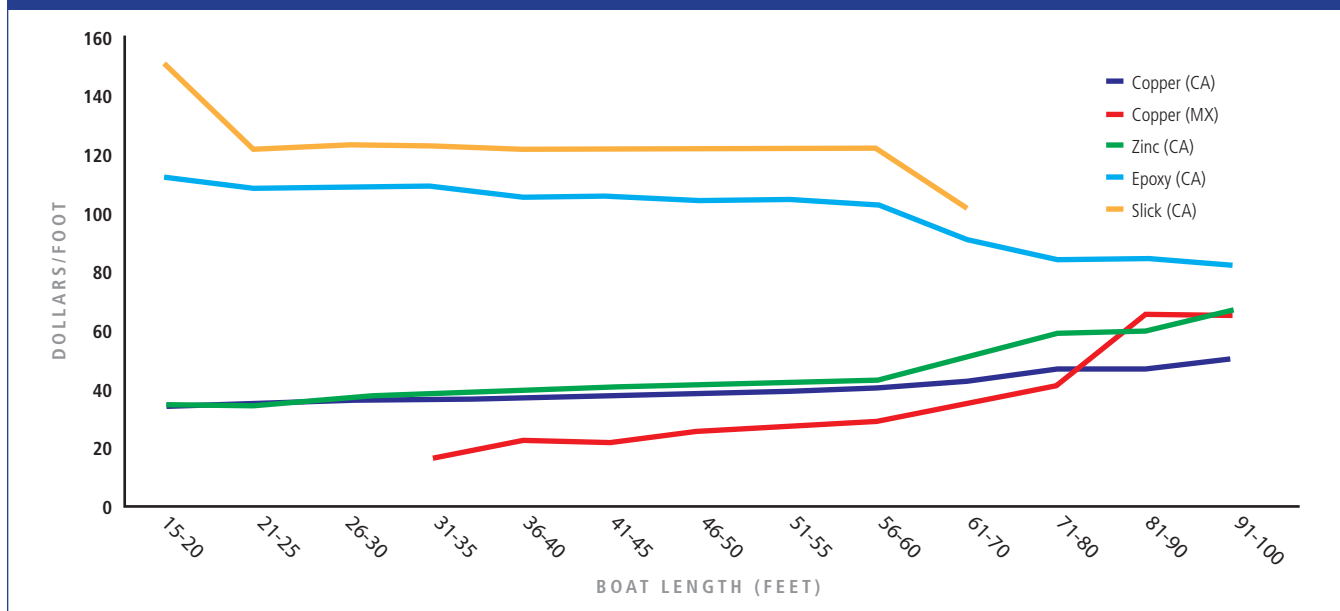
We also asked boatyards to break down their costs for hull preparation and coating application into labor, materials, environmental fees and other costs. Labor constituted the largest share of mean total costs for toxic coatings, representing 56% for copper (23-24 responses) and 57% for zinc (5 responses). Labor constituted a greater share of mean total costs for nontoxic coatings, representing 63% for both epoxy and slick coatings (3 responses for each). The greater share of costs allocated to labor for the nontoxic coatings may reflect specialized hull preparation (e.g. stripping old copper paint) and application techniques (e.g. special primers or rolling on coatings) that may be required for them. Materials costs ranged from 30% of mean total costs for slick coatings to 40% for zinc. Environmental fees ranged from 2% of mean total costs for epoxy to 5% for copper. "Other" costs also represented a small portion of the mean total costs to apply hull coatings, ranging from 0% for epoxy to 3% for slick.



Boat hauled out in Southern California boatyard

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FIG. 7. ■ BOAT YARD COSTS TO APPLY COATINGS



Slip Liners and Boat Lifts

Slip liners and boat lifts are alternative companion strategies to hull cleaning. They may replace toxic coatings on boats that are used for relatively brief periods, as the hull is isolated from sources of fouling organisms. Both can be customized to an individual boat's size and shape, which determines the cost. Slip liner prices ranged from an absolute minimum of \$700 to an absolute maximum of \$8000. Boat lifts had a much greater absolute cost range, from \$300 to \$110,000. Generally, slip liners were less expensive (average costs ranged from \$1,046 to \$6,800) than boat lifts (average costs ranged from \$3,319 to \$27,150). Slip liner companies responding to the survey were far more likely (100%) to remove equipment abandoned at a marina than responding boat lift companies (12%). Slip liner removal could be free or cost up to \$250; boat lift removal fees were not provided. Installation, shipping and maintenance costs also varied and would affect total costs for these risk management strategies. Boat owners should consult marina management regarding policies on slip liners and boat lifts when considering a purchase.

How do overall costs compare for copper, zinc and nontoxic epoxy hull coatings?

Using the data from marinas, hull cleaning companies and boat repair yards, we calculated relative, comprehensive costs for using each type of hull coating. Nontoxic slick coatings were not included, as there were too few responses for statistical validity. Anticipated service lives were not considered in the statistical analysis, because they vary among regions, among types of copper paints, and because very little data were available for alternative coatings.

Relative, comprehensive, average costs were found to be \$20.49 per foot for copper paints, \$24.99 per foot for

zinc paints and \$36.33 per foot for epoxy coatings. In other words, using a zinc paint would cost \$4.50 per foot more on average than using a copper antifouling paint. Using a nontoxic epoxy coating would cost \$15.84 per foot more on average than using a copper paint.

However, boat owners should also consider the expected service life when choosing among coating types. The anticipated, longer service life of nontoxic epoxy coatings may balance the higher, average costs calculated in our analysis. Economists studying the total lifetime costs of boat hull maintenance calculated that it would be less expensive to have copper paint in the first few years, but that savings would decline the longer the owner kept the boat because the copper paint must be replaced more often than a nontoxic epoxy coating. If the boat owner kept the boat for five years or longer, the difference in total lifetime costs for using copper versus nontoxic epoxy coatings would be fairly small.⁵⁰ In line



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Roll-on application of nontoxic hull coating in Southern California boatyard

with these predictions, the owners of a sail boat that received a nontoxic epoxy coating in our 2002 field demonstration⁵¹ reported in 2010 that they had saved \$2940 versus anticipated costs for a copper paint over this 8 year period.⁵²

How do boat movements affect risks?

Boat travel patterns

Boat traffic and lengths of visits at marinas can present a risk for transporting invasive species within and among regions. The level of risk will vary depending on the amount of traffic between locations.⁵³ Scientific findings suggest that the heavier the travel throughout a region, the more likely that invasive species will be transported.⁵⁴

Marinas reported regions from which their overnight slip rentals (as opposed to regular slip tenants) originated. This suggested general travel patterns:

- Northern California boaters most often visited the Delta and the Central Coast. Southern California was ranked third.
- Delta and Central Coast boaters travelled most heavily to the Bay Area. Southern California was ranked second for Central Coast boaters.
- Southern California boaters most often visited Baja California and Baja California Sur. The Bay Area was ranked third.
- A few boats from mainland Mexico travelled to Los Cabos and La Paz in Baja California Sur.

Such visits, which include overnight stays in marinas, may increase the risk of transporting invasive species via recreational boats. For example, invasive species found in Elkhorn Slough at Monterey Bay were likely introduced by boats traveling from San Francisco Bay.⁵⁵ Our findings suggest that risks for transporting invasive species extend all along the California coast and across the California-Mexico border. The lowest risk for transporting invasive species was for boats moving between the freshwater Delta and the marine Bay Area. Many organisms cannot withstand this salinity change.

Boating events

In addition to general boat travel patterns, holidays, fishing tournaments and seasons, boating races and other events can



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San Diego boat in Baja California boatyard

draw a significant number of boats out of their home regions. The 4th of July, Fleet Week and the Baha Haha race (San Diego to Los Cabos/La Paz), as well as Memorial Day, Labor Day, local yacht club races, the Newport to Ensenada race, and others were cited by marinas as large sources of visitors from outside the region. Marinas reported that boaters stayed overnight for some of these events. “Waypoint” marinas for long-distance races reported overnight stays up to four nights, and “destination” marinas reported stays up to 30 nights. There is a risk that boats attending such events will carry invasive species on their hulls.

Question 4. What role could education play in managing water quality and invasive species risks?

Education could play an important role in helping boaters learn how to manage risks to water quality and from invasive species. Educational programs and practical experience with environmentally friendly practices could enhance long-term marina tenants’ capacity to educate other boaters.

Boating event organizers could include environmental messages with registration confirmation, mass media, banners and other materials. For example, they could encourage participants to clean their boats’ hulls, bilges and bait tanks before leaving from and returning to their home regions to avoid carrying invasive species.

Boat repair yards, hull cleaners and marina managers could also educate boaters on how to manage water quality and invasive species risks. We asked each survey participant to estimate the percentage of their customers who were aware of nontoxic hull coatings 1-2 years ago versus at the time of the survey. All industry groups believed there had been an increase (Figure 8). Because they were able to make these estimates, we believe that boating industries discuss nontoxic hull coatings with their customers and could also encourage them to reduce risks of carrying invasive species.

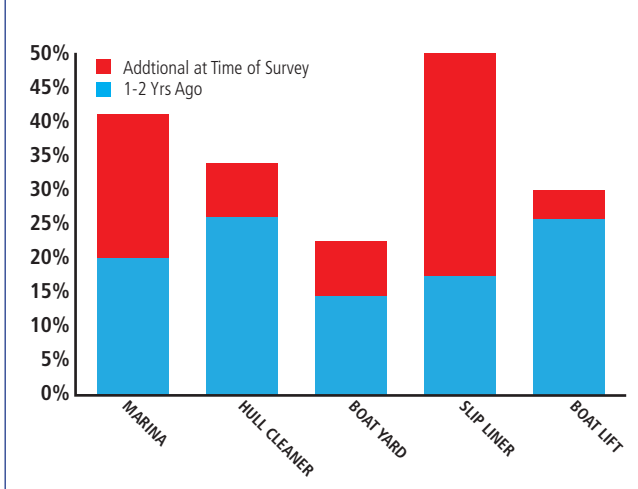
A statistical analysis for epoxy coatings found that



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Sacramento-San Joaquin Delta area boatyard/marina

FIG. 8 ■ PERCENT OF CUSTOMERS AWARE OF NONTOXIC COATINGS



increased awareness of nontoxic coatings influenced the choice of nontoxic coating positively. Interestingly, the relative comprehensive costs of each coating type (as described above), and location in California or Mexico, were not significant influences on the choice of a nontoxic hull coating. Results of this analysis suggest that educational programs may be effective in influencing boat owners' decisions on nontoxic hull coatings. Further, marinas, boat yards, hull cleaners and marine supply stores may be effective in assisting customers to learn about and choose nontoxic coatings.

Are some hull fouling species tolerant of copper?

Our recent review of scientific research found that some hull fouling species can tolerate copper antifouling paint.⁵⁶ Tolerance of this widely used hull fouling pesticide has implications for managing risks to water quality and native species, as well as costs for fouling control.

Numerous studies illustrate that copper tolerant

species are dominant in the competition for space on copper coated surfaces and reduce native species' diversity in copper polluted environments. One study found that the invasive bryozoan *Watersipora subtorquata* settled and grew on 64% of available surfaces that were coated with copper paint.⁵⁷

This study also found that *W. subtorquata* carried among its folds 22 species that were not able to attach directly to surfaces with copper paint. Further, species that appeared on both the copper paint and on *W. subtorquata* were 248 times more abundant on this invasive species. Thus, species that can grow directly on copper paints may create a surface on which less tolerant fouling species can settle and grow, allowing them to colonize a copper-painted hull.

Other evidence supporting the copper tolerance of invasive fouling species shows that they may dominate in a copper-polluted harbor.⁵⁸ Scientists demonstrated in one study that the advantage conferred by copper tolerance was limited to copper-polluted environments.⁵⁹ In another study native species' diversity decreased by up to 40% as copper concentrations in the water increased.⁶⁰

Copper tolerance is not limited to invasive fouling species. Our research in San Diego Bay found that by 6-12 months non-native and then native species settled and grew on experimental panels with copper paint.⁶¹ Many more examples and a more thorough discussion of the scientific literature on copper tolerance of hull fouling species can be found in, "Hull Fouling and Copper Tolerance – 2011 Scientific Review," at <http://ucanr.org/sites/coast/publications/>.

Parting Thoughts

Various hull coatings and companion strategies are available for managing risks to water quality and from invasive fouling species in California and Baja California. The capacity of boat repair yards and in-water hull cleaners to apply and maintain copper paints is widespread but capacity for alternatives to copper paints is limited in these regions. Alternative coatings may require special hull preparation, coating application and hull cleaning techniques and equipment. Copper paints are the least expensive hull coatings for boaters to use in the short term. A few boaters have had durable nontoxic hull coatings long enough to make them cost effective despite costs for converting from copper paint and for more frequent hull cleaning. As more boaters try these coatings for an extended time, more data will become available on how likely they are to be cost effective over the long term.

Adequate time and education for boat repair and hull cleaning companies to acquire the necessary skills and equipment to work with alternative hull coatings will be needed if restrictions on copper paint extend beyond northern San Diego Bay. Boat repair yards and hull cleaners who have experience with alternative coatings might serve as peer educators.

Boating industries reported increased customer

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Fouling on experimental panel from San Diego Bay. Note the red "leafy" bryozoan *Watersipora subtorquata*

awareness of nontoxic hull coatings. Awareness of nontoxic hull coatings had a statistically significant association with choosing them. Thus, boater education could play an important role in making choices that affect environmental quality.

Boating industry members and long-term marina tenants who are educated on water quality and invasive species transport risks, strategies for managing these risks, and alternatives to copper paints could play an important role in educating boat owners who make decisions on fouling control strategies for their boats. Similarly, boating events offer opportunities for educating arriving and departing boat owners on invasive species risks and how to reduce them.

Actively traveling boats may be better candidates for a toxic hull coating because they spend less time in the boat basin, reducing risks that discharges from such coatings could accumulate. Because they may encounter diverse species on their journeys, a well-maintained toxic coating could deter transport of hull fouling species beyond their native ranges. Given the body of scientific literature on copper tolerance of hull fouling species, boat owners who travel often may want to consider another type of toxic hull coating.

In contrast, boats that rarely leave the home marina are less likely to transport species among regions. If they use copper paints, they pose a greater risk for elevating dissolved copper levels in the home marina, because the paints are designed to leach copper continuously. Such boats would thus be better candidates for a nontoxic hull coating combined with frequent hull cleaning, a slip liner or boat lift in areas where copper pollution is a concern. When they do travel beyond the home harbor or region, the hull and underwater structures should be thoroughly cleaned before departure and again before return, if they have stayed awhile at another location. Similarly, boats that are active in local events but rarely or never travel beyond the home area would be candidates for a nontoxic coating combined with a companion strategy.

Making cost effective decisions on co-managing risks to water quality from fouling control methods and to coastal ecosystems from invasive species requires research-based information. This report and our article in the *Journal of Environmental Management*⁶² provide information to assist boat owners, boating industry members and policy makers in making these decisions for boats on California's coast, its Sacramento-San Joaquin Delta and major boating areas of the Baja California peninsula.

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